Crashworthiness Improvement of Vehicle Structures Enabled by Structural Bonding

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Dow Automotive Systems

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Overview

- Introduction
- Application specific structural adhesive
- Benefits of Crash Durable Adhesives (CDA)
- CDA modeling and simulation
- Full vehicle CDA application and evaluation
  - Stiffness improvement studies
  - Frontal Offset Deformable barrier
  - IIHS Side Impact
- Conclusions
Dow Automotive Systems is a technology-driven solutions provider offering:

- Safety and health performance
- Improved energy efficiency
- Reduced exhaust emissions
- Enhanced quality and appeal

**One part highly toughened CDA BETAMATE™**
Epoxy based
(Crash Durable Structural Adhesive)

**Two part repair CDA**

**Composite bonding**
Epoxy or PU based

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Market Drivers and Benefits

**BETAMATE™ Structural Adhesives**

- **Durability**
  - Conservation and retention of properties over the vehicle life

- **Driving Comfort**
  - Increased static and dynamic stiffness, improved ride and handling

- **Acoustic Comfort**
  - Reduction of structural born noise

- **Safety**
  - Enhanced load transfer and energy management capability

- **Environment**
  - Enabling weight reduction by optimum use
    - High strength steel
    - Panel thickness reduction
    - Multi material design
  - Spot welding and “other” joining optimization
  - Mass reduction up to 10 kg/vehicle
  - Process speed improvement of between 50 and 100%

- **Cost reduction**
History of Practiced CDA Bonding

First to market

1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

Normal CDA
- High viscosity
- CDA and semi-CDA

Daimler A-, S class
BMW 7 series
AUDI A4

Low viscous CDA
- High impact
- Humidity resistant
- High application speed

BMW 5 series
AUDI A8

Streamable CDA
- Lowest viscosity
- High impact
- Humidity resistant
- High application speed
- Jet spray

Wash-off resistant CDA
- High viscous yield, low viscosity
- CDA and semi-CDA
- Humidity resistant

Daimler E-, S-, C-class

Optimized adhesion
- Cohesive failure mode on CRS and GA
- High impact
- Humidity resistant

BMW 5 and 7 Series
GM Epsilon platform
Effect of CDA on Energy Absorption

Test conditions
- Room temperature
- 110 kg impacting section at initial speed of 11 m/sec

Geometry
- 50x140 mm section
- 380 mm long
- 30 mm spot weld pitch

<table>
<thead>
<tr>
<th>Material</th>
<th>Improvement over spot-welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSLA350 1.2 mm</td>
<td>18%</td>
</tr>
<tr>
<td>HSLA350 1.6 mm</td>
<td>10%</td>
</tr>
<tr>
<td>DP780 1.0 mm</td>
<td>12%</td>
</tr>
<tr>
<td>DP780 1.5 mm</td>
<td>10%</td>
</tr>
</tbody>
</table>
Adhesive Modeling and Correlation

Profile thickness: 1.0 mm
Bondline thickness: 0.35 mm
Impactor mass: 32.66 kg (72 lbs)
Impactor speed: 8.81 m/s (19.71 mph)

Modeling:
- Gurson material model captures the CDA behavior
- Bond line thickness 0.3-0.5 mm
- Tied contact definition

Correlation:
- Bonded closed box subjected to axial load
- Cohesive failure of adhesive
- F-D curve comparison in agreement
“Demonstrator” Car Project

NCAC – Baseline Full Frontal Crash

NASTRAN Baseline

Baseline Stiffness

LS-DYNA Baseline

Baseline IIHS side impact

Baseline frontal ODB crash

Light Weight Reinforcement Technology

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☑

BETAFOAM Structural Cavity Reinforcement

☑

☑

☑

BETAMATE Structural Bonding

☑

☑

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Bending  

Torsion
## Qualitative Stiffness Improvement

### Static

<table>
<thead>
<tr>
<th></th>
<th>Bending Stiffness [N/mm]</th>
<th>Torsion Stiffness [1/miliRad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>2162.7</td>
<td>0.66</td>
</tr>
<tr>
<td>BIW with CDA</td>
<td>3242.0 (+49.9 %) 78 m</td>
<td>0.85 (+28.8 %) 78 m</td>
</tr>
<tr>
<td>BIW with opt. CDA</td>
<td>3133.9 (+44.9 %) 45 m</td>
<td>0.81 (+22.7 %) 33 m</td>
</tr>
</tbody>
</table>

### Modes

<table>
<thead>
<tr>
<th>Modes Number</th>
<th>Freq. [Hz]</th>
<th>Mode Shape</th>
<th>BIW with full CDA</th>
<th>Increase</th>
<th>Optimum CDA</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (8#)</td>
<td>31.61</td>
<td>Full bending along vertical direction</td>
<td>37.76 (78 m)</td>
<td>+19.5%</td>
<td>35.72 (45 m)</td>
<td>+13.0%</td>
</tr>
<tr>
<td>4 (10#)</td>
<td>34.69</td>
<td>Full torsion with large deformation at rear side inner panel</td>
<td>-</td>
<td>-</td>
<td>48.40 (33 m)</td>
<td>+39.5%</td>
</tr>
</tbody>
</table>

**Gray:** baseline (22m)

**Orange:** contribution to **bending stiffness** (23m)

**Blue:** contribution to **torsion stiffness** (11m)

**Green:** contribution to **bending and torsion stiffness** (22m)
Vehicle CAE Impact Scenarios

1. IIHS Offset Deformable Barrier (ODB) impact

2. IIHS Side Impact
Baseline Evaluations

- Simulation model results observed close to published results by NCAC

<table>
<thead>
<tr>
<th>Test</th>
<th>Simulation</th>
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<tbody>
<tr>
<td><img src="image1" alt="Test Image" /></td>
<td><img src="image2" alt="Simulation Image" /></td>
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<tr>
<td><img src="image3" alt="Test Image" /></td>
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<tr>
<td><img src="image5" alt="Test Image" /></td>
<td><img src="image6" alt="Simulation Image" /></td>
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ODB Performance Improvement with CDA

Intrusion improvement

CDA Solution Baseline

Energy per unit time differences

ODB barrier internal energy rate comparison
Crash Durable Adhesive Designs Evaluated

**Adhesive application Designs:**

- **full CDA:** Blue + Green + Red (~ 100 m)
- **w/o front:** Green + Red (~ 83 m)
- **optimized:** Green (~ 55 m)

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**IIHS Frontal 40% ODB**

<table>
<thead>
<tr>
<th>Component</th>
<th>Baseline</th>
<th>CDA (~100 m)</th>
<th>w/o front rail CDA (~ 83 m)</th>
<th>Optimized CDA (~ 55 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footrest</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Toepan</td>
<td></td>
<td></td>
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<tr>
<td>Center Toepan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Toepan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brake Pedal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Inst Panel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Inst Panel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-B Pillar (closing distance)</td>
<td></td>
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</tbody>
</table>
With CDA design provides significant occupant compartment intrusion improvement.

Previously crash characterized front rail, may observe stiffer behavior and shift in first folding mode.

May require redesigning of bonded front rail so that it collapses progressively.

Includes redesigning parameters: metal thickness, strength and beads pattern.
CDA Designs Evaluated

Adhesive application Designs:

full CDA: Blue + Green (~ 100 m)

optimized: Green (~ 79 m)

Optimized bond line
Bond length ~ 79 m
Mass: ~ 650g
• Exhibits the maximum intrusion improvement of 61 mm (25%) at bottom side
• Intrusion of 15 mm (6%) at top side of the profile compared to baseline performance
- Improvement in intrusion has been reduced significantly (12%) compared to CDA design.
Conclusions

- CDA bonding provides superior load transfer between sheet metal parts, resulting in **improved crash performance**
- Crash durable adhesive provides superior **performance when compared to brittle adhesives**
- Structural bonding coupled with other joining methods and material selection, offers opportunity to **reduced weight** and enable **cost effective solutions**
- Automotive OEM’s and Tier’s can exploit maximum benefits of adhesive bonding by fostering adhesive bonding **as a critical design driver** at the beginning of the vehicle structure development
- Successful application of adhesives in front longitudinal members requires
  - Proper selection of steel thickness and steel grade
  - Proper joint design and adhesive that promotes increased energy absorption of the steel structure. The two can not be de-coupled